Subsurface Fluxes Beneath Large-Scale Convective Centers in the Indian Ocean: Coupled Air-Wave-Sea Processes in the Subtropics

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LONG-TERM GOALS

Long-term objectives are to assess the generation, evolution and breakdown of oceanic small-scale processes and how these contribute to larger-scale dynamics. A particular goal is to quantify the effects of such processes on mixing the ocean, both in redistributing heat, salt and chemical constituents and in redistributing momentum. Related to this goal is the quantification of energy losses due to turbulence dissipation and to internal wave radiation. To accomplish these goals, our group has developed various forms of unique observational instrumentation for use at sea, on ships, moorings and autonomous vehicles; this instrumentation has proven itself over many experiments. An emphasis is placed on fostering physical insight through analysis and development of simple physical models. Close collaborations with modelers (of both small and large scales) has led to deeper insight into many problems over the years.

OBJECTIVES

Specifically, the objectives of this project are to:

- quantify the detailed vertical and time-varying structure in both velocity and stratification of the Wyrtki jets. This measurement leads to estimation of *Ri* and potential parameterization of mixing;

assess negative feedbacks to atmospheric convection

- quantify sea surface cooling rates due to wind mixing and diurnal cooling;
- quantify sea surface cooling rates due to shear instability created by the highly-sheared currents, particularly the Wyrtki jets; and

assess positive feedbacks to atmospheric convection

- quantify sea surface heating rates (from both above and below) in thin near-surface fresh layers deposited by convective precipitation.

Significantly, such a detailed process experiment *had never before been attempted in the equatorial Indian Ocean*

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APPROACH

Extensive measurements of upper ocean currents, stratification and turbulence were made from R/V Roger Revelle over the fall 2011 MJO period in the equatorial Indian Ocean. These included measurements from customized instrumentation to include a clear depiction of the upper 5 meters of the ocean undisturbed by ship wake.

WORK COMPLETED

Revelle was the principal observational base for investigation of air-sea interactions associated with initiation and propagation of the Madden-Julian Oscillation (MJO) across the equatorial Indian Ocean.

A meeting of LASP air-sea PIs was held 24-26 June 2013 at Oregon State University (Corvallis, OR). A measurable outcome of this meeting was completion of a group paper submitted to *Bull.Am.Met.Soc.* in July 2013 (Moum et al., 2013).

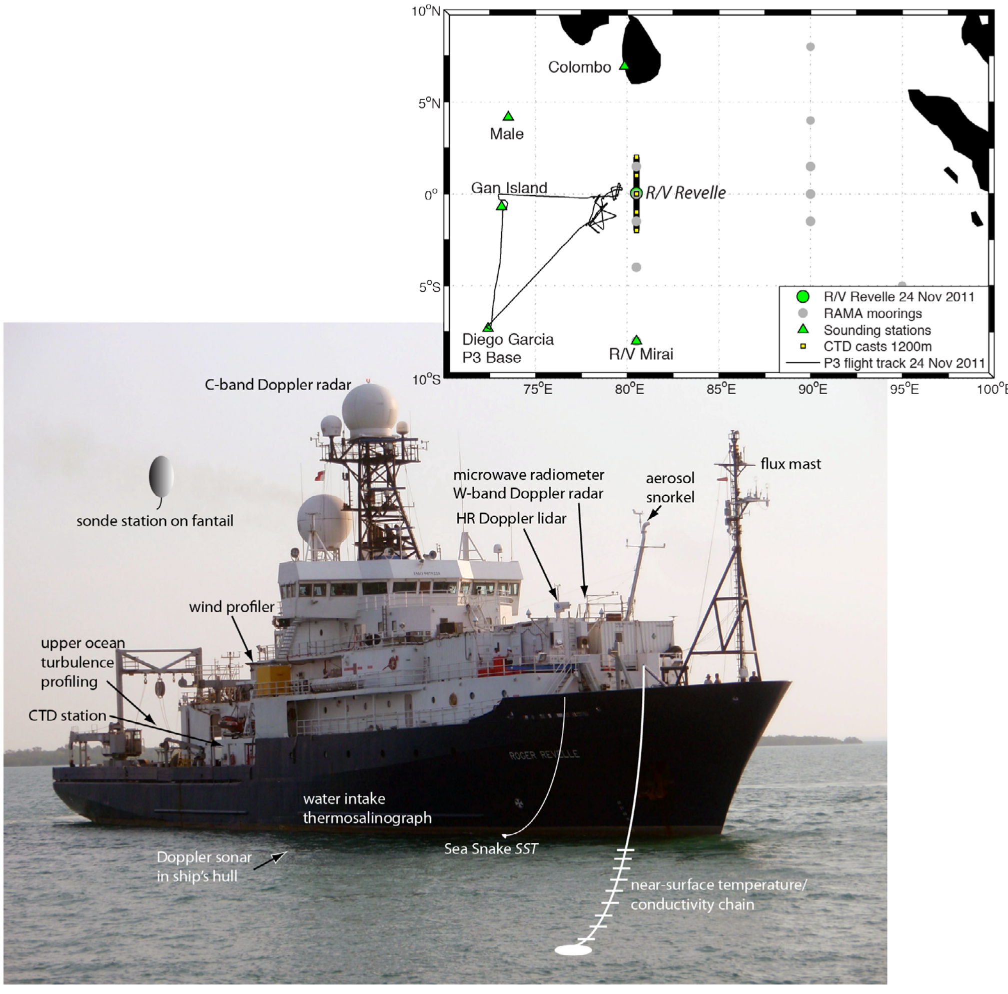

Figure 1 – Measurement systems installed on R/V Roger Revelle for DYNAMO/LASP. Inset map shows locations of land-based sounding stations, oceanographic moorings and the research vessels Mirai and Revelle during the intensive observation period of DYNAMO. The black line outlines the flight track of the NOAA P3 research aircraft on 24 November 2011.

RESULTS

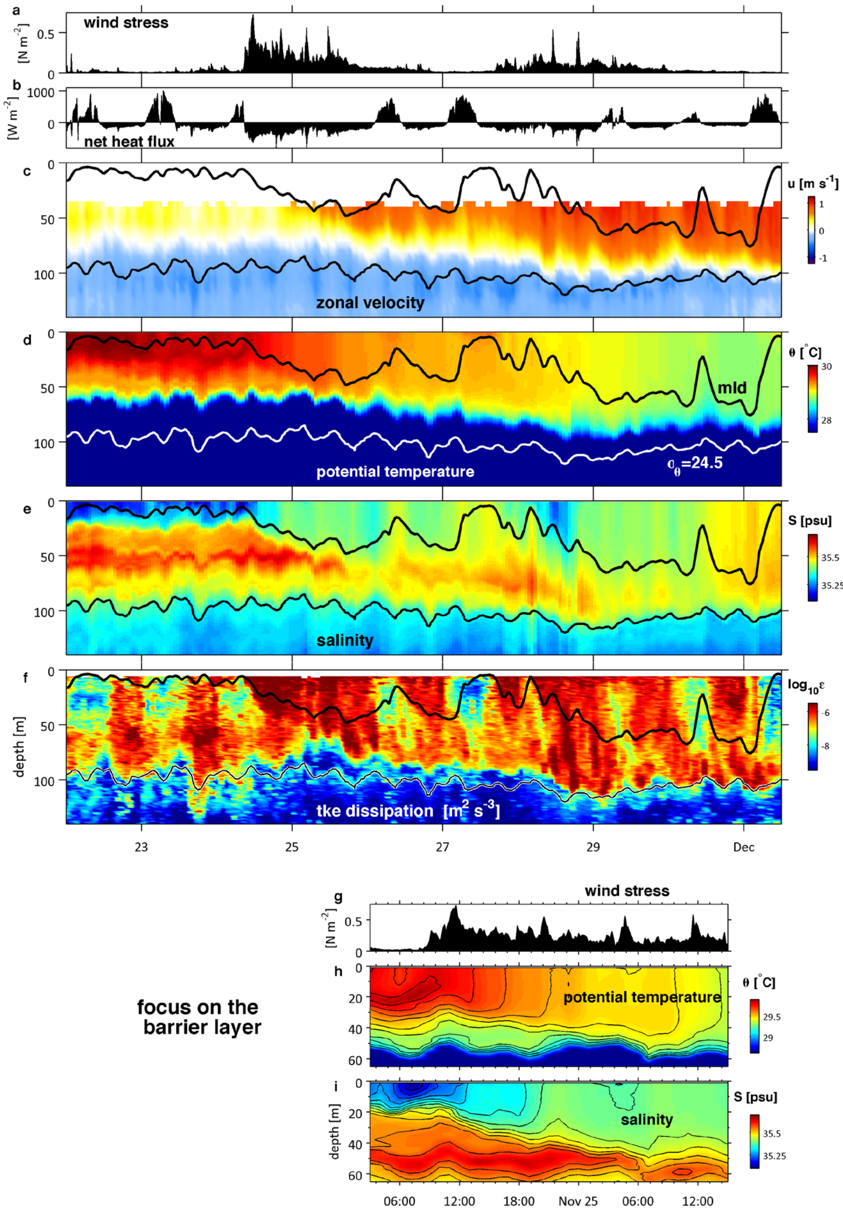

Figure 2 – Summary time series of upper ocean response to the first westerly wind burst of MJO2 at Revelle on 24 November 2011. a) The wind stress (total) appears as a step function change from <0.05 N m^{-2} to >0.5 N m^{-2} in a few minutes. b) Net surface heating. Net surface cooling lasted for more than 1 day, a rarity at the equator, though common during the passage of MJO events. c) Zonal current. The eastward surface current (the Yoshida-Wyrtki Jet) accelerated from < 0.5 m s^{-1} in about 1 day, deepening with time. The mixed layer is indicated by the black line, the potential density surface 1024.75 by the white line. d) Temperature. Mixed layer cooling was driven by combined atmospheric and subsurface cooling. e) Salinity. Salinification of the surface was driven by an excess of subsurface mixing over precipitation. f) Turbulence dissipation. At bottom are expanded plots showing the first 24 h following arrival of the wind burst. g) Wind stress. h) Temperature with temperature contours scaled to represent identical contribution to density as do salinity contours in i) salinity.

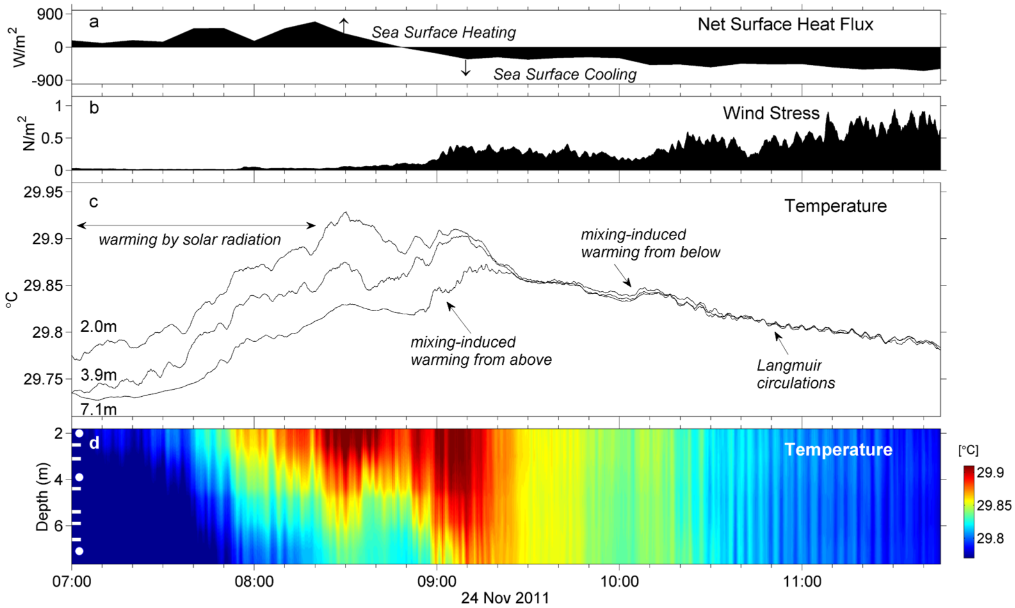

Figure 3 – Structure of the near surface of the ocean as the leading wind burst of MJO2 arrived at Revelle. a) Net surface heat flux. b) Surface wind stress. c) Ocean temperature at 2.0, 3.9 and 7.1 m (depths denoted by white dots in d). d) Image-color plot of temperature in the upper 8 m from sensors at depths indicated at left and sampling as they are profiling the water column with wave motion.

Efforts are focused on 4 main themes.

1) ocean response to the MJO (Qualitative results are depicted in Fig. 2, 3). Quantatively, mixed layer cooling by the wind burst is due 2/3 to atmospheric fluxes from above, 1/3 to entrainment by mixing of cool fluid from below

2) physics of the diurnal warm layer (Fig. 3). This is a 1D radiation plus mixing problem that presently depends on parameterized mixing plus generic solar transmission profiles, with insufficient understanding to conditions under which each dominates. Transmission profile plus near-surface mixing measurements from LASP/DYNAMO are being used to assess bounds on the problem.

3) Propagation of freshwater fronts. At some early stage, freshwater pools laid down by precipitating clouds (measured by C-band radar in LASP/DYNAMO) propagate as buoyant gravity currents (Fig. 4). An assessment of how these spread and mix to form a barrier layer is underway.

4) Overall, the ocean retains a signature of the MJO in the form of the Yoshida-Wyrtki Jet accelerated by the wind bursts, at the base of which shear-generated turbulence continues long after MJO passage. Continued cooling by this mixing appears to retard SST recovery.

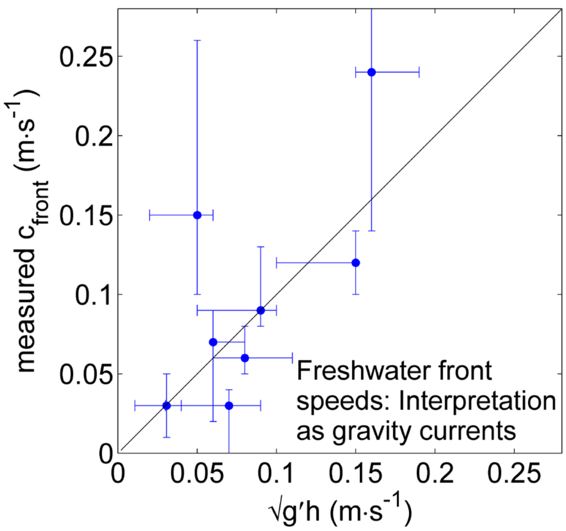

Figure 4 – Comparison of freshwater pool front speeds measured by tracking X-band radar frontal signatures and estimates based on a simple 2-layer buoyant gravity current model.

IMPACT/APPLICATION

These measurements will represent an important contribution to the long-term DYNAMO effort. We will produce a legacy data set that includes hourly-averaged turbulence diffusivity profiles.

RELATED PROJECTS

The Cooperative Indian Ocean Experiment on Intraseasonal Variability in the Year 2011 (CINDY2011), collected in situ observations aboard the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) research vessel *MIRAI* in late fall 2011. A coordinated regional field experiment was conducted in fall 2011 on the Dynamics of the Madden-Julian Oscillation (DYNAMO). The latter experiment was designed to observe the initial development of an MJO in the central Indian Ocean from a 4-month deployment on United States, Australian, Indian and Japanese research vessels. CINDY2011 and DYNAMO have similar scientific goals and observational requirements. The PI is working closely with DYNAMO and CINDY2011 PIs.

PUBLICATIONS

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